(Format No.3)

SUMMARY OF DOCTORAL THESIS

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Title: **Study on juice extraction from sweet sorghum (スイートソルガムの搾汁に関する研究)**

As the global warming is deteriorating and the price of petroleum is rising sharply, many countries are exploring the clean and renewable energy. Ethanol production from energy crops is an alternative to resolve the problems of global climate change and the terminability of fossil fuel. Sweet sorghum has the potential to be used as a renewable energy crop, but its short harvest period, poor storability, and higher transportation costs have prevented it from being utilized.

I proposed a sweet sorghum utilization system as followings. Sweet sorghum was chop-harvested by a forage harvester, and the chopped plants were extracted with an extractor. The juice was fermented to ethanol. The bagasse was pressed with a roll baler and airproofed with a bale wrapper as fodder silage. The silage would be made into total mixed rations (TMR) with a feed mixer in a center plant according to the needs of dairy farmers. The forage harvester, the roll baler, and the bale wrapper might employ the commercial machineries. However, it is necessary to develop an extractor and a mixer suitable for the system. Therefore, a roller-belt extractor for chop-harvested sweet sorghum, a gear-type extractor for whole plant of sweet sorghum, and a single-shaft paddle mixer for sweet sorghum silage were developed. In addition, the extraction characteristics and growth features of sweet sorghum and feed compositions of sweet sorghum silage were also investigated.

1. Development of a roller-belt extractor for chop-harvested sweet sorghum

A roller-belt extractor for chop-harvested sweet sorghum was designed and built. The total length of the extractor was 1.2 m, its overall width was 0.67 m, and its overall height was 1.04 m. Extraction experiments were conducted using the screening designs and the central composite designs. The extraction ratio (juice mass to input mass expressed in percentage) of the extractor increased with reduced cut length, decreased drive roller speed, and increased feed rate. The mean extraction ratio was 19.7±1.1% (Mean±SD) when the theoretical cut length was set to 17 mm, the drive roller speed to 6.3 rpm, and the feed rate to 1000 kg/h (maximum). The advantages of the extractor included simple construction, low costs, convenient feeding of chopped feedstock, and easy collection of the bagasse.

2. Development of a gear-type extractor for whole plant of sweet sorghum

A gear-type extractor suitable for whole plant of sweet sorghum was designed, built, and tested. The total length of the extractor was 0.65 m, its overall width was 0.40 m, its overall height was 0.65 m, and its total weight was 45 kg. A comparison of results using the roller-belt extractor and the gear-type extractor indicated no significant difference in accuracy to determine sugar content of sweet sorghum. The extraction speed was 9.3 s/plant, and the juice extraction ratio was 8.7%. When the extractor was used to determine the sugar content of sweet sorghum, the suitable sample number was 6 or more than 6 plants when the area of experimental plot was not more than 225 m^2.

3. Extraction characteristics and growth features of sweet sorghum

The extraction characteristics of the internodes and chopped materials of sweet sorghum were investigated using a tension-meter and a compression testing machine in order to determine the optimal harvest-time, and extract sweet sorghum efficiently. In addition, the effects of sowing time and fertilizer level on the sugar content of sweet sorghum were also investigated applying the gear-type extractor.

The hardness of the first internodes from top was the smallest in all the internodes of sweet sorghum. The internodes hardness showed an upward tendency with increasing the numbers of internodes. The sugar content increased from the first internodes to the sixth internodes, the maximum value appeared at 4, or 5, or 6 internodes according to the weeks after sowing, after that, the sugar contents showed a downward tendency with increasing the numbers of internodes.

The thin materials of chopped sweet sorghum are more advantageous than the thick materials in

order to extract sweet sorghum efficiently. The energy use efficiency of thin chopped-sweet sorghum was higher than that of thick chopped-sweet sorghum. A better linear logarithmic relation between the pressure and the juice extraction ratio existed when the chopped sweet sorghum was extracted (R^2=0.9429). In spite of the juice extraction ratio increased with increased the pressure, the energy use efficiency decreased with increasing the pressure. When the 100 g samples were extracted by the pressure of 9.8 MPa, the juice extraction ratio and pressure use efficiency were at their optimum states, 45.9% and 45.9 g/kg・MPa, respectively. The juice extraction ratio did not affect the sugar content of the juice.

It is suitable to sow two times for sweet sorghum in Tottori city in one year in order to prolong harvest period. The harvest period will come to three months, September, October, and November if the sweet sorghum was sown at the end of May and the beginning of July. The sugar content of the obtained juice would be more than 10%.

4. Ethanol fermentation from sweet sorghum juice

The conversion efficiencies of ethanol fermentation from High Sugar Sorghum and Super Sugar Sorghum juices were investigated using the *Saccharomyces Cerevisiae F5*. The maximum ethanol content in the fermented juice of Super Sugar Sorghum was 3.8% with 97.9% total sugar conversion efficiency at 48 hours after fermented compared with 3.8% with 82% conversion efficiency of High Sugar Sorghum at 24 hours after fermented. If considering of fermentation time, the ethanol content and conversion efficiency of Super Sugar Sorghum were 3.1% and 80% at 24 hours after fermented, respectively. Therefore, High Sugar Sorghum juices are better than Super Sugar Sorghum juices being used to ethanol fermentation.

5. Feed composition analysis of sweet sorghum and its silage

In order to determine the effects of juice extraction and ensiling on the feed compositions of sweet sorghum, the feed compositions of chopped materials, bagasse, chopped materials silage, and bagasse silage of two varieties sweet sorghum (High Sugar Sorghum and Super Sugar Sorghum) were analyzed and compared. After sweet sorghum was extracted, the contents of crude fiber (CF), acid detergent fiber (ADF), and neutral detergent fiber (NDF) increased, and the contents of non-fibrous carbohydrate (NFC) and nitrogen-free extract (NFE) decreased. Both chopped plants and bagasse were well fermented, and satisfied the standards for good silage. The NO_3-N contents of bagasse silages were lower than that of chopped-sweet sorghum silages. It implied that juice extraction improved the quality of sweet sorghum silage.

6. Effects of cultivation and ensiling time on nitrate nitrogen content of sweet sorghum

The effects of cultivation conditions (sowing time, N-fertilizer level, and harvesting time) and short time ensiling, on the NO_3-N content of sweet sorghum were investigated. The NO_3-N content of sweet sorghum was affected significantly by sowing time, N-fertilizer level, and harvesting time. The NO_3-N content increased with increasing the N-fertilizer application. The NO_3-N content increased from 2 weeks after heading (0.03%), and reached a peak (0.19%) at 6 weeks after heading, and maintained 0.07% until to 10 weeks after heading. The NO_3-N content of sweet sorghum silage lost about half of total within the beginning of 3 days. After that, it changed little.

7. Development of a single-shaft paddle mixer for sweet sorghum silage

A single-shaft paddle mixer for sweet sorghum silage was designed, built, and tested. The total length of the mixer was 2.0 m, its overall width was 0.6 m, and its overall height was 1.2 m. The slope angle of mixing chamber, the rotation speed of drive shaft, the angle between paddle plane and axial direction, and feed rate influenced the mixing performance of the developed mixer. The variation coefficient of the mixer was 18% setting the slope angle of mixing chamber to 1°, the angle between paddle plane and axial direction to 30°, the rotation speed of drive shaft to 52.5 rpm, and the feed rate to 1200 kg/h.

The objectives of the study were to ferment the juice to ethanol, and ensile bagasse as fodder after the chop-harvested sweet sorghum was extracted. In order to extract sweet sorghum efficiently, the suitable cultivation conditions and the extraction characteristics of chop-harvested sweet sorghum were determined, and the suitable extractors were also developed. In addition, the conversion efficiency of ethanol fermentation from sweet sorghum juice and the feed compositions of bagasse were also investigated. These results will help in optimizing the sweet sorghum utilization system and promote the use of sweet sorghum.